

# ID11- A 3D MAPPING, OBSTACLE AVOIDANCE AND ACOUSTIC COMMUNICATION PAYLOAD FOR THE AUV SPARUS II

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**Abstract**— This paper presents the new payload for Turbot, the SPARUS II AUV unit, manufactured by the University of Girona and recently acquired by the Systems, Robotics and Vision Group of the University of the Balearic Islands. The new payload has been entirely designed and integrated to host all elements necessary to perform visual 2D/3D mapping, optical (visual laser) object reconstruction, acoustic and visual obstacle avoidance, and acoustic localization and communication. Several experiments in shallow waters of Mallorca show the validity of the sensor integration and operation for all the required tasks.

**Keywords** — Autonomous Underwater Vehicle, Sonar, USBL, Stereo Vision, Laser.

## I. INTRODUCTION

In the last years, there is an increasing scientific interest in the exploration of the underwater environment. As technology evolves, better quality 2D maps and underwater 3D dimensional reconstructions can be performed using up to date hardware. This three dimensional reconstructions and 2D maps will not only help scientists to recognize the environment, but they will also enhance the performance of the navigation modules installed in underwater vehicles and help the vehicle to better understand the medium in which it is moving. Autonomous navigation can be addressed with a well calibrated set of sensors and a navigation software able to interpret the incoming data, to guide the vehicle thrusters along a required path, whilst avoiding possible collisions. The navigation sensor suit can be formed, not only by inertial or dead-reckoning sensors, but also aided by absolute position sensors or visual SLAM (Simultaneous Localization and Mapping) [1] algorithms, which are used to correct periodically the odometry estimated by the former instruments. Concerning the tasks of 2D/3D mapping and object reconstruction, additional instrumentation is needed for video recording and 3D point cloud extraction. These two reasons have led us to design a new payload for Turbot, a SPARUS II AUV [2] unit acquired in December 2014. SPARUS II is a 1.6 m long torpedo-shaped vehicle with three thrusters, two horizontal for surge and heading, and one vertical to maintain its depth. This last thruster also allows the vehicle to remain static at a certain depth regardless of its surge speed. Its original sensor suite is formed by a DVL (Doppler Velocity Log), an IMU (Inertial Measurement Unit), a GPS (Global Positioning System), a pressure sensor and a Wi-Fi access point, as well as a 50 meter long Ethernet umbilical cable for wired connection if necessary. Its open-source software architecture COLA2 [3] is built on top of the ROS middleware. The new payload presented in this paper has been especially designed to host all the required instrumentation to perform autonomous navigation, 2D/3D mapping of the seafloor, object reconstruction, obstacle avoidance and acoustic localization/communication. The new equipment added to the payload are: an usb hub, an acoustic transducer linked to an USBL, a laser stripe, a Miniking sonar, and an ethernet stereo rig.

## II. BACKGROUND

The Systems, Robotics and Vision group of the University of the Balearic Islands is currently involved in two Spanish research projects, ARSEA (TIN2014-58662-R) and MERBOTS (DPI201457746-C3) [4], which require an AUV capable of performing online robust three dimensional reconstruction of the underwater environment, autonomous navigation, object reconstruction and recognition, and underwater global positioning and communication. ARSEA is focused on surveying and controlling areas of special ecological, social or economical interest, for example, with very specialized tasks such as photo-mosaicking and building 3D models of seagrass meadows, and inspection of ship/aircraft wrecks or deteriorated infrastructures. These 2D and 3D models are inserted in an augmented reality integrated pilot console specially designed to command the vehicle in ROV mode, as the pilot was immersed in the aquatic environment. In the context of the aforementioned projects, neither

the available sensors nor the software architecture were enough to accomplish with their requirements. For example, there was no obstacle avoidance control or underwater cameras to perform visual exploration, mapping or aiding to the intervention. So the minimum needed payload has to include a stereoscopic system, lights for imaging at high depths, underwater communications (e.g. acoustic communications), a laser stripe to detect and build 3D objects in regions with very bad visibility, and an obstacle avoidance sensor

## III. DESIGN

Turbot AUV is an open hardware and open source robot, based on the ROS middleware. The original software architecture, provided by the manufacturer is COLA2, a layered control architecture formed by a control layer, a navigation layer, a safety layer, and a teleoperation layer. This software is based on a single EKF (Extended Kalman Filter) to fuse all the inputs from the available sensors in the AUV to compute its dead reckoning. Its waypoint-based autonomous navigation allows the user to predefine a mission and send it to the robot. The vehicle has two physical spaces available for further improvements or hardware additions, one dry is located inside its hull towards the nose, and another wet which is the nose itself. The cap of the cylinder is already pre-drilled to fit up to eight M11 underwater rated connectors (such as Subconn). The next sections detail the designed expansion choices and their hardware implementation.

### A. The Visual System

In order to solve all degrees of freedom of the resulting reconstructions, three dimensional mapping of the seafloor requires a stereoscopic system, if the visibility conditions are optimal, or a triangulation solution, such as using a laser projector, in case of poor visibility conditions. If only one camera was used, a bathymetry can complement the 3D model. However, the bathymetry would need an unknown scale factor. A stereo rig formed by two cameras Allied Vision Technologies G-283C, with a full resolution of 1936 x 1458 pixels at 35 frames per second were placed in the payload. These ethernet cameras are connected each to a different hardware interface and through dedicated underwater gigabit ethernet cable and connectors. The housing for the cameras had to be designed to withstand the same water pressure as the AUV, e.g. two hundred meters. The chosen material was aluminium, which was later anodized to endure on salt water. Artificial light is needed to record underwater scenes at more than ten meters or during the night. Two 4320 lumen LED lights from Mangrove AVS-6L were chosen. Each light head needs 40 W, so a relay board controlled by an Arduino was added to the dry payload system to manage the aforementioned lights. Apart from the lights, a slightly tilted laser stripe projector formed by a 532nm, 40 mW ZM18B green laser from Z-Laser was also added in our designed delrin housing and for the same water depth. With both systems, we are able to reconstruct underwater scenes even without features, thanks to the laser projector, and from altitudes up to three meters [5].

### B. Obstacle avoidance system

Once the navigation system has been improved thanks to the USBL and a visual mapping system provided by the stereo rig, an obstacle avoidance system is desirable so that the vehicle does not hit an underwater structure, rock or wall. A Tritech Miniking imaging sonar has been mounted on the half bottom of the wet payload. This sonar has a vertical beam width of 40°, and a horizontal beam width of 3°. Although it can operate 360°, we only use the forward  $\pm 45^\circ$  to look for obstacles. The CAD payload design can be seen in figure 1 and its complete integration in the vehicle is shown in figure 2.

### C. Acoustic Communications System

Nowadays, most AUVs still rely on dead-reckoning systems (i.e. DVL, Visual Odometers, inertial sensors) which are subject to cumulative drift. Autonomous navigation and intervention underwater needs improved localization modules to withstand the increasing demand on mission duration and higher accuracy. Commonly used absolute

positioning devices such as GPS or LBL (Long Base Line) are available to the end users to localize the vehicle. However GPS does not work underwater due to the rapid energy absorption of the electromagnetic waves underwater, and an LBL system require a complex infrastructure deployment and calibration prior to use. On the other hand, USBL (Ultra Short Base Line) acousticmodemovercometheseproblemsbysimplifyingthe needed equipment and narrowing the distance between the acoustic transponders. AUSBLsystemformedbyafixedUSBLheadthat has four or five transceivers (hydrophones). This head is normally mounted on the hull of a vessel with known absolute position often provided by GPS (e.g. surface vehicles). Then, another mobile modem transceiver is installed on a vehicle which needs to be located and a permanent communication link with the base. A USBL is not only capable of the mobile modem localization from the USBL head, but also provides acoustic communication. A USBL modem 18/34 from Evologics was also installed in our payload. This unit can establish a communication link in a radius of 3500 m, and achieves a maximum throughput of 14 Kbps. The USBL head localizes the modem, and from the software, this position is send via the acoustic link to the vehicle, to be integrated in its own navigation filter. Apart from sending the localization, other service messages are send from the central laptop connected to the USBLheadtothevehicle,suchas,turnon/off thelights,turnon/off the laser, or safety recoveries in the case a mission has to be cancelled. The navigation data (position estimated by the vehicle EKF filter, battery status, depth, etc) are also sent from the vehicle to the USBL head.

#### IV. SOFTWARE ARCHITECTURE

The control architecture software of the AUV, based on COLA2[3], supplied with the vehicle, consists of a layered control structure with the following main layers: navigation, control, safety and guidance. Our new architecture complements and improves the original one in 3 main aspects: the navigation and localization modules, the safety layer, the Sensor aggregator (a new module that centralizes the reception of all the data given by all the sensors), and an obstacle detection module.

The new navigation solution simplifies the localization problem splitting it into

two EKF filters, to cope with different sensor update rates and the different nature of their provided data. Then, the system is easier to customize, debug, assess and evaluate.

In the first EKF, (called EKF odom), the predictions are computed using Newtonian mechanics and the updates are made with the dead-reckon information, such as the velocity updates from the DVL, a visual ORB tracker [6], the rotation rates provided by the IMU, plus the position updates in z from the depth sensor.

The second EKF (called EKF map) uses the same inputs of the EKF odom plus the GPS and the USBL position data received in the vehicle. These two additional sensors give absolute positions (with no orientation) with respect to a global coordinate frame ( the map coordinate frame), and have an update frequency much lower than the other sensors listed in the previous paragraph. As mentioned in previous paragraphs, EKF odom is essential to correct the missynchronization of the last USBL position sample with the current EKFmapupdatestate,causedbythedelaysintheacousticcommunications.

The position of the robot given by EKF odom responds to the sensors that emit at higher frequencies but it may drift. Whenever a new absolute measurement either from the GPS or from the USBL is available to the EKF map filter, the resulting robot global position is adjusted.

The sensor data is fed to the Sensor Aggregator, a module that checks that the sensor readings are well structured and input in the proper order at the boot of the vehicle. Filtering and data preprocessing is also handled here.

The safety layer has been reinforced with new and modular, value and frequency monitors. These monitors can be connected to any of the sensors to validate if the irreturned values are in between the established minimum or maximum, as well as the minimum frequency they should be working at. If the monitored device does not comply with the requirements, a recovery action is called. The recovery action is also user-configurable, and can range from a sensor reboot to an emergency surface of the vehicle.

Finally,the obstacle detection module uses the imaging sonar installed in the new payload. The echoes received from the sonar are parsed by our software and checked for possible obstacles. If there is any, the sonar software sends a message to the navigation layer to take the appropriate decisions.

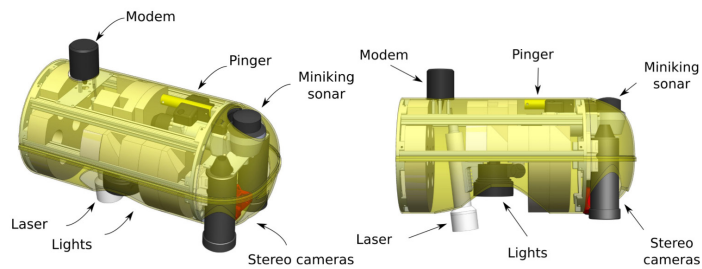


Fig. 1: Payload CAD design showing the location of the Laser, the lights, the cameras, the modem, the pinger and the sonar.

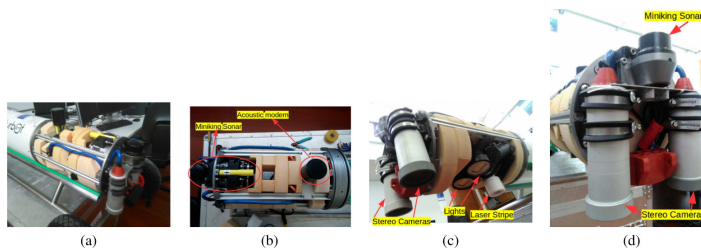


Fig. 2: (a) Finished payload integration. (b) Top view showing the Sonar and the acoustic transducer. (c) Bottom view showing the cameras, the lights and the laser stripe, all looking downwards. (d) Frontal view showing the cameras and the sonar.

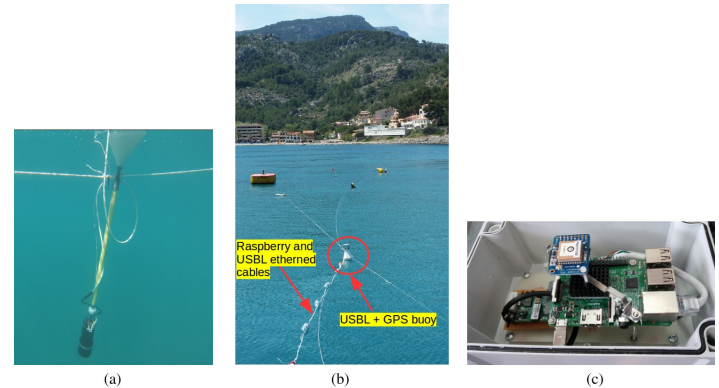


Fig. 3: (a) The USBL buoy photographed from the water. (b)-(c) Two different perspectives of the buoy and the AUV from the shore. (c) A photo of the Raspberry and GPS card mounted over the USBL buoy.

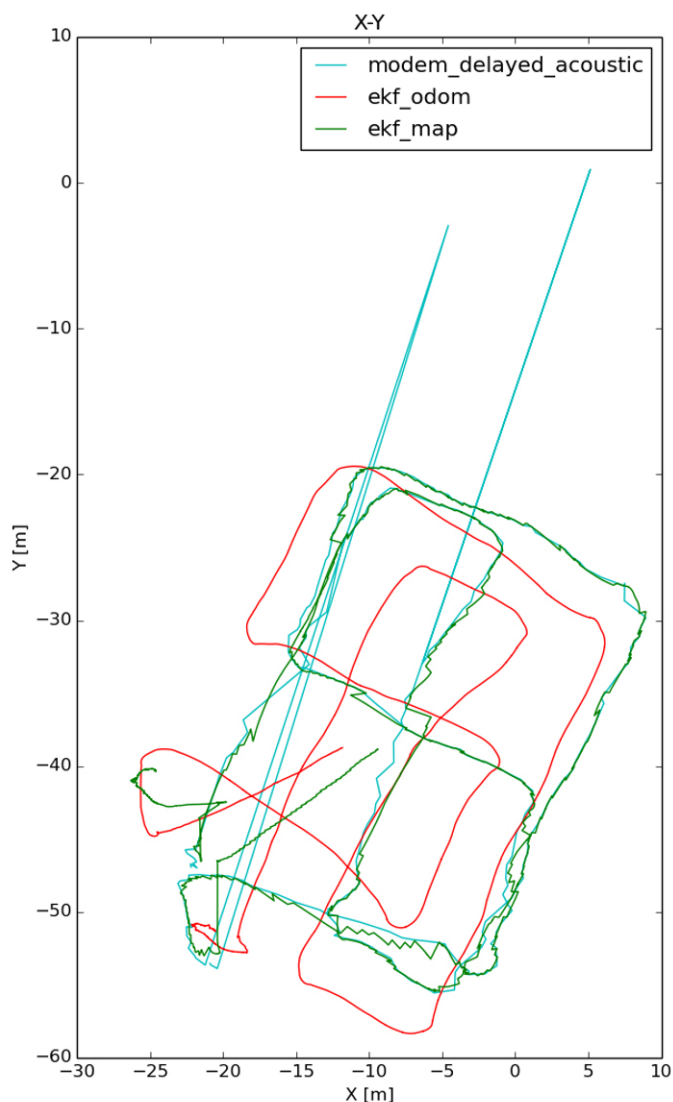


Fig. 4: The vehicle trajectory according to the USBL modem and the two EKF.

## V. EXPERIMENTS

A wide range of tests have been carried out in the shoreline of Mallorca to prepare the upcoming experiments of the project MERBOTS, testing the new payload, the acoustic communications and the navigation/localization design. Forthcoming additional tests have been programmed to be conducted soon to verify the performance of the visual 3D mapping algorithms. In our real testing scenarios, the USBL head unit is hanged from a powered buoy, which has a GPS managed by a Raspberry Pi3 unit, mounted in a sealed plastic box on the top of the buoy. The USBL and the Raspberry card are both connected to an ethernet switch located on the shore via a long cable, where a control laptop is also connected. Thanks to this switch, the USBL, the Raspberry card and the laptop are all connected at the same ethernet address range. This laptop is in charge to manage the USBL vehicle positions and to send them back to the robot transformed to the world coordinate frames system (e.g. in latitude, longitude, depth). Figure 3-(a) shows the USBL buoy fixed to a wire which is tied, in one end, to a big buoy delimiting the military harbour in Port de Soller, while the opposite end is tied to the harbour breakwater. This set up is shown in figure 3-(b)). Figure 3-(c) shows the GPS and the Raspberry card mounted on the top of the buoy. Figure 4 shows the vehicle trajectory estimated by the USBL (modem delayed acoustic), the ekf odom and the ekf map, corresponding to one experiment in Port de Soller. Although the position estimates given by the USBL modem presents a couple of outliers, the EKF map has been able to eliminate them while it rectifies the odometric trajectory.

## VI. ACKNOWLEDGEMENTS

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